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JOHN F. KENNEDY SPACE CENTER

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KSC DESIGN CRITERIA
FOR REUSABLE
SPACE VEHICLE UMBILICAL SYSTEMS

DESIGN ENGINEERING DIRECTORATE

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KSC DESIGN CRITERIA
FOR REUSABLE
SPACE VEHICLE UMBILICAL SYSTEMS

Approved by:

Associate Director for Design
Design Engineering Directorate

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHN F. KENNEDY SPACE CENTER

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INTRODUCTION

The purpose of this document is to organize, for use in the design of reusable umbilical systems, the experience and knowledge accumulated in space programs at KSC. This document reflects KSC technical experience, lessons learned, and information to induce greater consistency, reliability, and efficiency in the design effort.

1.0 SCOPE

This criteria covers the preferred general design objective for reusable space vehicle umbilicals. Discussion of umbilicals is limited to the carrier(s) and plate(s), couplings, connectors, withdrawal and retract devices, handling mechanisms and facility control equipment. The service arm(s) or their equivalent mechanism and associated equipment are not covered.

2.0 APPLICABLE DOCUMENTS

a. Umbilical Connect Techniques Improvement Technology Study, NAS10-7702.

b. KSC Equivalency List, KHB 4430.1.

c. Kennedy Approved Parts List, KAPL.

d. KSC Bonding and Grounding Standard, KSC-STD-E-0012.

e. Standard for Lightning Protection, KSC-STD-E-0013.

3.0 DEFINITIONS

For the purpose of uniformity of nomenclature, and precise definition, the following terms and their definitions are set forth for use in this document and associated correspondence:

a. Coupling - A device, consisting of two halves, which permits transfer of fluid across, and disconnection at, an interface.

b. Connector - A device, consisting of two halves, which permits engagement and disengagement of electrical circuits at an interface.

c. Interface - A region of mating, or boundary, between separating or cooperating elements, established by a governing characteristic; such as ground-to-vehicle interface, physical interface, or responsibility interface.

d. Umbilical - An adjective, relating nouns to the task of provisioning fluid and electrical requirements at the interface(s) between ground facilities and a flight vehicle.

e. Carrier - A device which groups coupling and connector halves together to provide a common means for their positioning, retention, unlocking, and separation. The term is commonly used in relation to the facility side of umbilical interfaces.

f. Plate - A device which groups coupling and connector halves together to provide a common means for retention. The plate is a passive device, containing cooperating but usually immobile portions of positioning, locking, and separation machinery. The term is commonly used in relation to the vehicle side of umbilical interfaces.

g. Umbilical Assembly - The mated carrier and plate, containing all couplings and connectors for a specified umbilical region of the vehicle.

h. Service Arm - A retractable structure, usually moving in a horizontal path, used to provide either umbilical requirements, or access, or both to the vehicle. (Commonly called access arm, umbilical arm, or swing arm, depending upon whether it provides services for access only, umbilical(s) only, or both, respectively, to the vehicle.)

i. Tail Service Mast - A retractable structure used to provide umbilical requirements to the lower portion (tail) of a space vehicle. Movement is usually a rotation about a pivot point away from the vehicle in a vertical plane.

j. Umbilical System - The functional assemblage of all items required for providing vehicle fluid and electrical requirements. Usually includes service arm(s), or equivalent mechanism(s), umbilical carrier(s), and plate(s), couplings and connectors, all separation, withdrawal, and retraction devices, control equipment, the control fluids and electrical signals, and all interconnecting lines across the service arm(s) or the equivalent mechanism.

k. Inflight - A modifier, applied to connote an occurrence or function after vehicle liftoff.

l. Liftoff - A term designating the instant of vehicle flight at which vehicle contact is terminated with all areas of holddown and/or support devices. Commonly called "first motion" of the vehicle.

m. Preflight - A modifier, applied to designate an occurrence or function before vehicle liftoff.

n. Riseoff - An adjective, applied to a device to denote that its actuation is solely caused by vehicle vertical motion.

o. Ground Control - The equipment, fluids, or signals, provided for command or control purposes, which are neither on board nor originate on board the launch vehicle.

p. Handling Mechanism - A device used to provide positioning, manipulation, and dead weight support of an object.

q. Launch Processing System - Consists of those operating consoles, data handling and display equipment, and the associated transmission system, configured to issue commands and analyze and display response data required in checkout and operation of Ground Support Equipment (GSE) and flight hardware.

4.0 GENERAL DESIGN OBJECTIVES

It is desirable that the following objectives be included in space vehicle umbilical systems design.

4.1 UMBILICAL SERVICES

Any fluid or electrical service routed through an umbilical service arm or equivalent mechanism, should be required to be disconnected prior to booster engine ignition and should not require reconnection to abort safely on the pad. For those services which must remain connected to achieve a safe abort, the preferred method of routing would be through riseoff type umbilical connections.

4.2 MATING

Design consideration should be given to minimizing the time required to achieve umbilical assembly connection and verification. Factors that should be considered: number of steps required, number of component parts to be installed or manipulated in the connection process; availability of, and accessibility with, mechanical handling aids; available working space; operating personnel requirements; overall safety requirements; alignment requirements; and the adaptability to automated verification.

4.2.1 HANDLING AND ENGAGEMENT. Rapid handling and engagement is necessary in order to minimize impact on the ground turnaround and launch support crew size. The ease with which an umbilical assembly is mated and connected to a vehicle should consider weight, torque requirements, manual force required for connection, and rigidity of electrical cables, flex lines, propellant flex lines, Environmental Control System (ECS) ducts, etc.

4.2.2 ALIGNMENT. Umbilical assembly design should not require critical manual horizontal, vertical, or parallel alignment for mating. Self alignment is an objective.

4.2.3 VERIFICATION. Mated umbilical assemblies should be designed to allow quick and reliable verification of integrity.

4.3 WEIGHT

Umbilical parts should be designed as light-weight as feasible to minimize launch induced loads and ground handling requirements.

4.4 LOAD BALANCE

Connections should be located on or within the carrier so that forces required for disconnect or retention to the vehicle are evenly distributed about the locking, release, and ejection mechanisms. The same consideration should also be given in the design of the handling systems.

4.5 CONTAMINATION PREVENTION

Both halves of all couplings should incorporate internal poppets for protection of the system from debris during the launch, flight, and recovery operations. It is preferred that debris poppets be spring-loaded to the closed position and be opened automatically by the engagement of the two coupling halves. The poppets will close automatically as the two coupling halves are separated.

4.6 PURGES

Electrical umbilical connectors should be provided with an inert environment. Cryogenic connections may be purged as required to prevent moisture condensation and resulting ice buildup or liquefaction of air.

4.7 SIDE LOADS

Design and use of carriers and plates should be in a manner that prevents side loads on the connectors or couplings.

4.8 TRACKING LOADS

As a goal, all loads associated with tracking of vehicle motion by the umbilical assembly and attached hardware should be borne by the vehicle.

4.9 LEAK DETECTION

Umbilical couplings should utilize primary and secondary seals and have sensing ability to ascertain primary seal leakage.

4.10 LEAKAGE DISPOSAL

Disposal of hazardous media leakage from couplings should be provided during vehicle servicing.

4.11 ELECTRICAL CONNECTORS

It is desirable that electrical connectors be dead faced and self aligning. Data bus, power, and command functions should be in separate connectors. Connectors contained in the carrier should not be self locking.

4.12 GROUNDING

Umbilicals should be grounded in accordance with the requirements of the KSC Bonding and Grounding Standard, KSC-STD-E-0012 and the Standard for Lightning Protection, KSC-STD-E-0013.

4.13 LIGHTNING CURRENT PATHS

Umbilical connections above the base area of a space vehicle should be eliminated or minimized to reduce the electrical paths through the vehicle from a lightning strike on the facility structure.

4.14 LAUNCH ENVIRONMENT PROTECTION

Umbilical carriers, plates, couplings, connectors, service lines, cables, etc. should be protected from launch environment and inflight effects.

4.15 COMPONENT SELECTION

Components used in the design of space vehicle umbilical systems should be chosen from those listed in the Kennedy Approved Parts List (KAPL), and the KSC Equivalency List (KHB 4430.1). Use of unlisted components should be justified on an individual basis, approved by NASA-KSC Design Engineering, and supported by a qualification program.

4.16 CORROSION CONTROL

The atmosphere at KSC contains a high salt content that is readily deposited on exposed surfaces. This, combined with substantial moisture and generally high temperatures, results in an ideal environment for extensive corrosion of metals. The designer should provide for corrosion control due to these environmental conditions. In particular, the designer should select materials and coatings and should design equipment for the prevention of crevice, stress, and galvanic corrosion.

4.17 MAINTAINABILITY

Material and its installation should be designed to achieve the required launch vehicle turnaround objectives.

4.18 ACCESSIBILITY

The designer should provide for ready access for operating, testing, fault-detecting, repairing, and replacing components. The design should allow these functions to be performed without interfering with other components or assemblies.

4.19 VALVE POSITION FEEDBACK

All remotely operated valves used for umbilical ground controls should have position feedback signaling. Command and feedback signals should not be combined in the same connector or cable, regardless of source.

5.0 DESIGN CRITERIA

The ultimate goal in umbilical system design is to have no inflight disconnects, preflights are preferred. Current technology makes this goal unrealistic; as a compromise the following preferences (paragraphs 5.1 and 5.2) are presented as guidelines.

5.1 INFLIGHT UMBILICAL ASSEMBLY(S)

When the vehicle requirement can not be met by a preflight umbilical assembly only, the preferred design for all inflight disconnects is the riseoff type with a fixed elevation ground carrier.

Preference, second to having all inflight disconnects of the riseoff type, would be to have only those services which must remain connected to achieve a safe abort routed through the riseoff type umbilical assembly(s). Those remaining inflight services should be routed through a tail service mast.

As a third preference for cases in which riseoff type umbilicals would not be consistent with the overall vehicle design, a tail service mast should be used for all services.

5.1.1 RISEOFF TYPE UMBILICAL ASSEMBLY

a. The riseoff type umbilical is characterized by the inflight umbilical plate being disconnected vertically in the direction of flight and as a direct result of vehicle motion. The ground carrier remains at a fixed elevation after mating and during launch.

b. The vehicle plate will be subjected to relative motion with respect to the fixed portion of the launcher due to the various induced forces (wind, temperature changes, fuel loading operations, engine firing effects, etc.) on the vehicle between the time of umbilical mating and launch. The horizontal motion after mating should be accommodated by allowing the ground carrier of the assembly to track the vehicle. The vertical motion is accommodated within the coupling and connector design.

c. The ground carrier should incorporate initial alignment pins that will engage with mating receptacles. The design of the pins should assure that the ground carrier is aligned with the vehicle plate before any of the couplings and connectors start to engage. The carrier should be elevated for connections by self locking mechanisms such as worm screw actuators. Each of the couplings and connectors should also incorporate self-alignment provisions to ensure proper final engagement.

5.1.1.1 Umbilical Couplings and Connectors. For the fluid couplings, vehicle motion should be accommodated by a sliding seal between the coupling halves. The electrical connector halves on the ground carrier should be spring loaded against the vehicle half, to accommodate vehicle vertical motion. This spring load should be designed to overcome the dynamic loading due to engine generated noise and vibration.

5.1.1.2 Cryogenic Couplings

a. All cryogenic couplings should be of the slip type with dual self-forming lip seals. A tertiary seal should be provided to contain a gaseous purge adjacent to the dual seals. The gaseous purge would prevent cryo-pumping and ice buildup on the sliding seal surface.

b. The cryogenic coupling should not require the application of additional insulation after mating. The volume between the dual lip seals should be vented through a tubing connection of the ground side. This vent tubing could then be monitored for leaks during verification of the connect phase when the coupling is tested by pressurization internally with gaseous helium. The couplings should also provide for the mounting of leak detection devices.

c. The mounting provisions for the ground half of the coupling and the attached flexible duct should allow lateral and angular motion with respect to the ground carrier to assure that the coupling halves will align during engagement and disengagement. The vehicle half of the coupling should be rigidly attached to the vehicle plate.

5.1.1.3 Electrical Connectors

a. It is preferred that the data bus electrical connector as well as command circuits connector be separate from the electrical ground power connector. All connectors should incorporate carrier mounting alignment provisions and gaseous nitrogen purge provisions.

b. The connector design should incorporate the necessary springs to insure proper connection while accommodating vertical relative motion. All connectors should be of the dead face type.

c. The back-shell and faceplate should be purged with gaseous nitrogen. Strain relief devices should be incorporated in the back-shell design of all connectors to prevent stress loading of wire terminations.

5.1.1.4 Protective Blast Door (Ground). This door (or doors) should be actuated after the vehicle has risen to an altitude sufficient to provide clearance for door movement. The door(s) outer surface should have structural and thermal integrity to withstand the direct impingement of the engine exhaust during the launch transient. The door(s) should be closed completely before the vehicle has risen to an altitude sufficient for direct exhaust impingement on the umbilical couplings. A breakaway lanyard attached to the vehicle is a preferred source of door actuation energy.

5.1.2 TAIL SERVICE MAST. The tail service mast is characterized by the horizontal (i.e. perpendicular to the direction of flight) release direction of the couplings. It is preferred that all couplings and connectors be contained in a single assembly. This umbilical assembly should enclose the electrical connectors sufficiently so that an inert gas purge can be maintained. Purging of cryogenic couplings should be utilized to provide hazard proofing and the prevention of ice buildup.

5.1.2.1 Umbilical Couplings. Because there is no appreciable relative motion between the ground and vehicle carrier, the choice of couplings is not limited. However, experience has shown that it is preferrable to use ball and cone couplings (with the ball half located in the ground carrier and the cone half located in the vehicle plate) with springs for low pressure, bellows for medium pressure and pressure-balanced slip couplings for pressures over 500 psig. Dual seals should be utilized and the volume between the seals vented through the ground side to provide for leakage verification. The coupling should have provisions for mounting leak detection devices.

5.1.2.2 Electrical Connectors. It is preferred that the data bus electrical connector as well as command circuits connector be separate from the electrical ground power connector. All connectors should incorporate carrier mounting alignment provisions and gaseous nitrogen purge provisions. All connectors should be of the dead face type. The back-shell and faceplate should be purged with gaseous nitrogen. It is desirable that strain relief devices be incorporated in the back-shell design of all connectors to prevent stress loading of wire terminations.

5.1.2.3 Locking and Ejection Devices. It is preferred that the vehicle plate and ground carrier should be secured by a single locking device.

a. None of the couplings or connectors should incorporate individual locking devices. Alignment of the vehicle plate and ground carrier should utilize guide pins. These guide pins should engage before the locking device or couplings. Separation of the ground carrier should be accomplished by pneumatic release of the locking device (with a mechanical backup provided). The preferred method for ejection is by pneumatic pistons in the ground carrier.

b. The locking device should be of a collet or four ball-lock design and have the capability to engage the carrier to the vehicle plate at a distance far enough away to allow guide pin alignment before the couplings and connectors halves mate. Preferrably, a manually operated system should translate the locking device and guide pins to maintain the ground carrier in alignment with the vehicle plate while the assembly and all couplings and connectors are engaged simultaneously. Visual means should be provided for positive locking verification. Because some of the couplings and connectors would be in-flight disconnects (i.e. required for safe on-pad aborts) and because they would be unlocked and ejected laterally from the vehicle after liftoff, it is highly desirable that the carrier lock(s) have primary, secondary, and tertiary release modes (fail operational/fail operational).

5.1.2.4 Handling and Control Systems

a. If required, for launch vehicle erection, provisions should be incorporated for the necessary articulation to retract the mast out of the way. Provisions should also be made for local manual control of the mechanisms to allow rapid engagement of the ground carrier to the vehicle carrier. The retraction of the mast should also provide protection of the ground system from the vehicle engine exhaust blast.

b. The ground control system should utilize redundant valving, power supply, and fluid stored energy supply.

5.2 PREFLIGHT UMBILICAL ASSEMBLY

In the preflight umbilical assembly it is preferred that all couplings and connectors be contained in a single assembly. The vehicle plate and ground carrier should be secured by a single locking device. None of the couplings or connectors should incorporate individual locking devices. Alignment of the vehicle plate and ground carrier should utilize guide pins. These guide pins should engage before the locking device or couplings. Separation of the ground carrier should be accomplished by pneumatic release of the locking device (with a mechanical backup provided). The preferred method for ejection is by pneumatic pistons in the ground carrier. The umbilical assembly should enclose the electrical connectors sufficiently so that an inert gas purge can be maintained. Purging of cryogenic couplings should be utilized to provide hazard proofing and the prevention of ice buildup.

5.2.1 UMBILICAL COUPLINGS

a. Dual seals should be utilized and the volume between the seals should be vented through the ground side to provide for leakage verification. The couplings should have provisions for mounting leak detection devices.

b. Fluid couplings conveying high pressure (500 psi and over) media should utilize balanced pressure design features to minimize thrust loads. Low pressure (150 psi or less) couplings should utilize springs for the sealing force and medium pressure (150 to 500 psi) couplings utilizing bellows for the sealing force should be considered.

5.2.2 ELECTRICAL CONNECTORS. It is preferred that the data bus electrical connector as well as command circuits connector be separate from the electrical ground power connector. All connectors should incorporate carrier mounting alignment provisions and gaseous nitrogen purge provisions. All connectors should be of the dead face type. The back-shell and faceplate should be purged with gaseous nitrogen. It is desirable that strain relief devices be incorporated in the back-shell design of all connectors to prevent stress loading of wire terminations.

5.2.3 LOCKING DEVICES. The locking device should be of a collet or four ball-lock design and have the capability to engage the carrier to the vehicle plate at a distance far enough away to allow guide pin alignment before the couplings and connectors halves mate. Preferrably, a manually operated system would translate the locking device and guide pins to maintain the ground carrier in alignment with the vehicle plate while the assembly and all couplings and connectors are engaged simultaneously. Visual means should be provided for positive locking verification.

5.2.4 HANDLING SYSTEM. If required a counterbalanced boom system is the preferred method of providing support of the dead weight of the ground carrier, cables, and hoses during manual engagement of the guide pins and locking device. The counterbalanced boom should also provide powered forces to withdraw the ground carrier away from the vehicle after release and carrier ejection.

5.2.5 CONTROL SYSTEM

a. It is preferred that the ground control system utilize redundant valving, power supply, and fluid stored energy supply. Design of the system should be for the normal operation in the following sequence: unlock of the locking device, ejection of the ground carrier and separation from the flight plate, withdrawal of the ground carrier and service lines to permit a clearance envelope between the vehicle, and subsequent service arm retraction. The redundancy should provide for a backup mode to accomplish the normal sequence. Should normal pneumatic carrier unlock or ejection fail, a mechanical device should accomplish the unlock or ejection in normal sequence.

b. The ground control system should incorporate both local manual control and remote control and monitoring for operation in the final prelaunch sequence. The system should be able to provide data inputs to the Launch Processing System (LPS).